

CERTAIN PROBLEMS RESULTING FROM EFFECTS OF ACCELERATION  
DURING SPACE FLIGHT (EFFECTS OF CUMULATION AND ADAPTATION)

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## ABSTRACT

The author performs an investigation in order to make a comprehensive study of clinico-physiological, biochemical, hematological, roentgenological, and pathomorphological changes occurring in the organism of animals subjected to one-time or repeated effects of acceleration. The tests conducted used 50 dogs and 13 monkeys. A maximum tolerable duration to an acceleration of 12 g units was established for the monkeys. A correlation of changes in the roentgenological, clinical, and pathomorphological pictures was established. Repeated exposure to acceleration in the organism of an animal may cause various adaptive and cumulative damaging effects. A thorough study of this problem is deemed an important task.

Space flight has engendered many problems, one of which is the influence had by the cumulative and adaptive effects of acceleration on the organism of man and animal. Investigation into this very complex problem is of definite practical scientific interest. Information in available literature gives evidence of the fact that, on one hand, the resistance of an organism may increase when subjected to the effects of acceleration repeatedly and, on the other hand, repeated exposure to acceleration may lead to cumulation of negative effects. /1

Armstrong and Heim (1938) indicated that if the effects of acceleration are repeated several times in the direction head--pelvis over a period of several continuous days an increase in tolerance is noticed. When the effects were repeated during a single day the authors noted a lowering in the resistance of the organism. According to data provided by A. P. Popov (1939) ground training, including physical exercises and rotation in a centrifuge, causes resistance to the effects of acceleration in pilots. When executing acrobatic flight maneuvers, trained pilots created somewhat greater g-loads than did untrained pilots.

In the work of A. B. Flekkel' and A. M. Odinov (1949) there is also an indication of the possibility of increasing acceleration tolerance by repeated

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\*Numbers given in the margin indicate the pagination in the original foreign text.

rotation on a centrifuge. In their opinion the results of training as evaluated from the subjective feelings of those subjects tested become manifest after 3--4 sessions. The maximum benefit was noted by the start of the 9th-10th sessions and lasted one month after the training. However, when the acceleration was repeated at short intervals the phenomenon of cumulation occurred in the organism. /2

V. I. Babushkin, V. B. Malkin, and V. V. Usachev (1956) showed that the physiological reactions of an organism as acceleration is repeated acquire an adequate nature corresponding generally in proportion to the strain involved. According to data provided by P. K. Isakov (1957) a man's resistance to the effects of acceleration rises as he performs repeated acrobatic flying maneuvers which gradually become more complex.

At the same time in available literature there is to be found information suggestive that the g-loads may have harmful consequences for an organism. Nearly all researchers working in this area observed hemorrhaging in the integument following the effects of transverse acceleration (Buhrlen, Z., 1937; Duane, Z. D.; and others, 1955; Clarke and others, 1959; Kotovskaya, A. R., Suvorov, P. M., and others, 1962; Barer, A. S., 1962; and others) and conjunctiva of the sclera of the eyes (Jacobs, H., Cannigham, C., Conover, D., 1957), and the appearance of moist rales in the posterior sections of the lungs and even hemoptysis (Cherniack, N., Hyde, A. S., 1961; Muller, G., 1961; Watson, I. F., Cherniack, N., 1962).

Naturally the degree and nature of the disorders described by different authors were not the same and were affected by the different conditions under which the experiments were conducted. With repeated effects from acceleration, according to B. M. Savin (1966), in some animals increased resistance was observed and in others a marked decrease with different degrees of change in the functional condition of the brain centers.

The experiments conducted with animals by I. M. Khazen, E. M. Kogan, and A. S. Barer (1963) are of interest. These experiments showed that frequently repeated effects of acceleration caused deep morphological changes in many organs and systems to develop. Under the influence of acceleration of the same force but with greater intervals between tests, the morphological changes were much smaller in extent.

Many researchers attach great importance to the duration of the effect of acceleration. Wood, Lambert, and Code (1947) established that accelerations of 8--12 G's acting in the direction head--pelvis and lasting for 15 sec did not cause cumulative phenomena in dogs, despite the fact, that, they were experienced daily over a period of 26 days. At the same time these accelerations, when acting over a longer period, were accompanied by considerable deterioration in the condition of the animals.

Therefore even a very incomplete review of available literature on the subject shows that there is no unanimous opinion concerning the consequences of repeated exposure to acceleration. On one hand, data is submitted which gives evidence of the possibility of adaptation in man to the effects of

acceleration and, on the other hand, it is admitted that there is a possibility of cumulation of negative effects. Facts are presented to show <sup>/3</sup> the occurrence not only of functional changes but also of coarse structural disorders in tissues. However, it is altogether obvious that the occurrence of some degree of change in an organism is determined by the acceleration systems and the extent of acceleration, the direction of the vector, duration, frequency of repetition, etc. Clarification of the various aspects of this problem is of definite practical interest in the development of systems for training men to become accustomed to accelerations.

The purpose of our investigation was to make a comprehensive study of clinico-physiological, biochemical, hematological, roentgenological, and pathomorphological changes occurring in the organism of animals when they experience single or repeated accelerations.

Tests were conducted using 50 dogs and 13 monkeys. The direction of the accelerations was chest--back (+Gx). The dogs were subjected once to an acceleration measuring 8 G's and lasting 3 min (1st Series) and once to an acceleration measuring 12 G's and lasting 1 min (2nd Series). They were also subjected to repeated accelerations measuring from 3 to 12 G's according to the following schedule: 3 G's--180 sec; 5 G's--180 sec; 6 G's--150 sec; 8 G's--120 sec; 10 G's--90 sec; and 12 G's--60 sec (3rd Series) (Table 1). The intervals between rotations was 36--48 hours.

Table 1

Distribution of Animals Depending on Regimes of Effects

Regime of Effects	Total Number of Animals	Number Killed
8 G's for a period of 3 min (1st Series)	17	14
12 G's for a period of 1 min (2nd Series)	19	16
From 3 to 12 G's (3rd Series)	14	14
Totals:	50	44

In tests conducted using monkeys a maximum tolerable duration to an acceleration of 12 G's was established. The gradient of increase was 0.15 G's/sec (A. R. Kotovskaya, P. V. Vasil'yev, B. A. Lapin, et al., 1963).

The results of the tests showed that single and repeated accelerations caused the occurrence in the organisms of physiological changes in similar directions but manifested in varying degrees. The clinical observations made

by B. V. Batrakov of animals subjected to single accelerations measuring 8 G's and lasting for 3 min and 12 G's lasting for 1 min allowed the detection of /4 several changes in behavior and also in separate organs and systems of organs. In several dogs periods of general depression delayed reactions, and sluggishness were noted, varying in duration. In some animals the periods lasted 1.5--3 hours and in others the entire first day after they had been subjected to the accelerations (B. V. Batrakov). The mucous membranes were hyperemic. On the conjunctiva of the eyelids and the mucous lining of the pharynx there were individual spots of hemorrhaging. In 50% of the dogs obtusion was noted in the percussion note in the lower dorsal sections of the chest, weakening of vesicular respiration, and moist rales of a microvesicular nature. In all animals a slight dulling of the tones of the heart and in some cases systolic noise in the apex was noted. With palpation of the organs of the abdominal cavity in most of the animals painfulness of varying intensity was registered in the area around the kidneys. However, a clinical urinalysis of these animals revealed no pathological symptoms. Nothing unusual was noticed about the other organs in the abdominal cavity. The temperature and weight differed very little from their initial values.

The indicated deviations in certain organs and systems were of brief duration. The changes around the heart disappeared first. Hemorrhaging in the mucous membranes lasted 1--3 days after rotation was terminated and acute pain in the area of the kidneys 1-2 days. During the next 3--5 days only a certain amount of nervousness was noted in the animals during palpation of this area. First the rales disappeared in the lungs and the degree of obtusion and weakening of vesicular respiration decreased. In general the duration of the after-effects was from one to 12 days.

An analysis of the information obtained from medical observation of the animals used in the 3rd Series gives evidence of the varying nature and degree of disorders which occurred. During the first two days after the accelerations of from 3 to 6 G's the behavior of dogs differed little from normal and on subsequent days, after accelerations of 8, 10, and 12 G's had been experienced, it changed noticeably. The animals became more sluggish and indifferent to their surroundings. In some animals the delayed reactions and sluggishness were noted during the first 1--3 hours after the effects were felt and in others they were experienced on the following day. In this way the change in the overall condition of the animals during the period when the after-effects were being experienced was determined not only by the strength of the stimulus used, but also by the resistance of the animals to the effects of acceleration.

The difference in weight of the animals between the last day of rotation and the initial value was in 60% of all cases negative and within the range of from -1.1 to 9.5%. In the remaining dogs it was positive and fluctuated from +2.8 to +5.4%.

All animals were divided into three main groups according to the degree to which clinical changes were manifested: the first group, with slight /5 pathological changes (3 dogs), and the second group, with moderate changes (9 dogs), and the third group with marked changes (2 dogs).

In the animals in the first group during the process of all rotations and also after the termination of the experiment the following changes were noted. The behavior of the dogs was not significantly different from that at the beginning of the experiment. The body temperature was normal. After termination of the accelerations, usually beginning with the second day of rotations on the centrifuge (acceleration of 6 G's for 150 sec), marked hyperemia of the mucous membranes of the mouth and pharynx and conjunctiva of the eyes were noted and small, isolated points of hemorrhaging appeared on the mucous membranes of the lower lids, the pharynx, and, less often, of the tonsils. After the third or fourth day of rotation it was noted that the tonsils were somewhat enlarged. The degree to which the above-mentioned changes were manifest and also the amount of hemorrhaging were apparently caused by the extent of the acceleration. No deviations in the other organs and systems were noted.

In animals in the second group, just as was the case in all other dogs of the trained series, it was characteristic that changes occurred in the visible mucous membranes. In nature they were the same as in the animals of the first group, however, the degree to which they were manifest was somewhat increased. Beginning with the 1st-3rd days of rotation and on subsequent days after the accelerations had been experienced, hyperemia of the conjunctiva, the mucous membranes of the mouth and pharynx, and, in some cases, of the anal opening was observed.

On the mucosa of the lower lids, the tonsils, and the pharynx separate points of hemorrhaging were found. However, in some cases numerous hemorrhages of a confluent type arranged in bands were noticed on the mucosa of the pharynx. Moreover, there was observed an increase and thickening of the submaxillary lymphatic nodes. The tonsils in most cases also had a tendency to increase somewhat in size. In the lungs, as a rule, after 2--3 days of rotation obtusion of the percussion note in the lower sections of the dorsal surfaces of the lungs (from the fifth rib and lower) was noted. Respiration in most of the animals during the first 2--3 days of rotation remained vesicular and on subsequent days, in many cases, a local weakening of respiration and the appearance of single and, as a rule, moist, microvesicular rales were observed.

No deviations with respect to the heart were noted in most animals. Only in a few cases was a slight weakening of tones or unstable systolic noise in the apex noted after the termination of rotation.

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During palpation of the organs of the abdominal cavity painfulness was noted in the area around the kidneys in almost all animals. At first (after the second day of rotation) the dogs exhibited some apprehension when this area was explored. Later this apprehension became even greater and was accompanied by a clearly defensive reaction. In a few cases painfulness in the area around the kidneys was so severe that the animals exhibited a very strong defensive reaction on even a very superficial palpation. However, /6 no pathological indicators were found when the urine was subjected to clinical test. In some cases protein in traces up to 0.03% in strength appeared. Moreover, in one dog, which had been subjected to an acceleration of 10 G's, there was noted an icteric coloring of the sclera of the eyes and in another

dog, on the fourth day after rotation, there was noticed painfulness on palpation of the right side of the inguinal area which continued also on the fifth day of training and the first day after training was terminated. The body temperature during this time remained normal. The pathological deviations which were noted were of a passing nature and usually disappeared rapidly. The period of recovery usually lasted in most cases from one to three days and less frequently from five to ten days.

Included in the third group were two dogs exhibiting stable pathological changes. They accounted for 14.3% of the total observations made. Clinical data from an examination of these animals confirmed laboratory analyses of the **urine and the blood**. In one dog pathological changes were noted in the liver and in the other, in the lungs and kidneys.

Veterinary examination of the animals made possible the identification of changes which, in most cases, were conditioned apparently by stable phenomena. This assertion is confirmed by the results of roentgenological and morphological examination of the lungs and other organs.

An X-ray study was made of the organs of the chest by P. N. Ivanov 20--30 min after the termination of rotation and also during the period when the after-effects were being felt (up to 60 days). In the lungs a strengthening of the radical and pulmonary patterns, especially in the caudal half of the pulmonary area, and also signs of lessening of the pneumatic process could be seen. All changes registered in the photos were determined by the extent and the duration of the accelerations. When the acceleration was of the order of from 3 to 8 G's, significant readings from the X-ray photos were very minor and brief in duration. The effects of a single acceleration measuring 12 G's in the 2nd Series and also the accelerations of 10 and 12 G's in the 3rd Series caused many noticeable changes which were most clearly expressed immediately following rotation but also lasted for a period of 5--7 days. Unfortunately the materials obtained did not make it possible to perform a quantitative evaluation of the changes which were noted or a comparative analysis of the changes associated with single or repeated accelerations.

A comparison of the data from roentgenological examination of the lungs and the results of physical observations was conducted with the help of auscultation and percussion. In most cases the existence of weakness in respiration and the occurrence of moist rales were accompanied by noticeable signs of pathology in the X-ray photos. It is an interesting fact that the indicated correlation was especially marked during the first one or two days. Later the deviations from normal, which were found in the lungs through the use of physical methods of examination, in most cases, did not have clear 7 confirmation in the X-ray photos.

It is important to note that the indicated clinical and roentgenological discoveries were confirmed in a pathomorphological examination of the test animals. The most clearly expressed morphological changes in the lungs of the animals were noted after a single acceleration of 12 G's lasting 60 sec.

As can be seen the effects of single and repeated transverse accelerations

caused changes in the condition of the animals which were uniform in their course but different as to the degree to which they were manifest. The changes in the behavior of the animals and in their overall condition were determined by the size and duration of the effects and also the individual resistance of the dogs to the accelerations. The changes which were noted in a clinical status apparently were the result of development of various pathological disorders in the vascular system and the parenchymatous elements of organs.

Physiological examinations were conducted to trace the nature of changes in separate reactions of the organisms of the animals with single and repeated transverse accelerations and to evaluate the importance of the initial functional condition prior to rotation. It should be noted that the physiological reactions as a result of single accelerations have been studied to a sufficient degree. Therefore, the data from examinations obtained during repeated accelerations (pulse rate, respiration rate, EKG, and gas exchange) were used by us for comparison with physiological reactions during the accelerations having different signs according to value in the cycle involving repeated rotation. The frequency of the heart beat in animals in the initial state fluctuated within rather wide limits (from 88 to 224 beats/min). On achieving accelerations of a constant force ("platforms") of 8 and 12 G's, the pulse rate was found to be within the limits of 198--208 beats/min. With an acceleration of 8 G's the pulse increased by 56.7--73.2% and with an acceleration of 12 G's by 98% in comparison with initial values.

In the series of tests in which the accelerations were repeated the heart beat in the initial state had a tendency to increase from test to test. Thus, prior to the first rotation it was, on an average,  $134 \pm 17.2$  beats/min and prior to the fifth rotation,  $153 \pm 28.9$  beats/min. With accelerations of from 3 to 12 G's the pulse rate was within the limits of 197--233 beats/min. We were not able to detect a direct dependence between the value of the acceleration and the gradual increase in pulse rate. The lack of a strict correlation between the increase in pulse rate and the increase in acceleration can apparently be explained by the high level of pulse frequency in the initial state when the pre-test preparations and outfitting the animals acted as a signal for the dogs and were accompanied by significant tachycardia (A. R. /8 Kotovskaya and Ye. M. Yuganov, 1962).

A comparison of the reactions of heart rhythm in animals exposed to acceleration equal in force (8 and 12 G's) once and then to a training cycle showed the following changes. With a single acceleration the pulse rate was in all cases lower than with the same strain induced in a cycle of repeated rotations. However, the initial functional state of animals in these experiments varied. Thus, the mean pulse rate prior to the single rotation was much lower than prior to corresponding tests in the 3rd Series which was the training series. Prior to the single rotation on the centrifuge it was 105--115 beats/min and in the training series, 153--166 beats/min (Table 2).

As can be seen from Table 2, in the training series of tests the increase in the number of cardiac contractions during the accelerations was approximately half the number when the acceleration was applied once.

Table 2

Comparison of Pulse Rate Prior to and During the Effects  
of Single Accelerations with the Same Accelerations in the  
Training Series of Tests (Mean Data)

Frequency of Cardiac Contractions							
Nature of Effects of Acceleration	Number of Animals	Prior to Effects of Acceleration of 8 G's	During the Effects of Acceleration	Increase in %	Prior to Effects of Acceleration of 12 G's	During the Effects of Acceleration of 12 G's	Increase in %
Single	24	115	185	+60.8	105	208	+98.0
Repeated	16	166	221	+33.1	153	227	+48.3

Note: Pulse rate prior to rotation taken as 100%.

In an analysis of the respiration indicators of the animals with single and repeated accelerations, no dependence was found between the change in respiration rate, the value of the acceleration, and the initial condition of the animals.

During accelerations which were constant in force ("platforms") the amount of air inhaled and the need for O<sub>2</sub> exceeded the initial value or approximated it. During the period when the centrifuge was being braked an increase was noted in the cited indicators in comparison with the background level (Table 3).

Table 3

Increase in Amount of Air Inhaled in a Minute (MOD) and Need for O<sub>2</sub> During Centrifuge Braking after Accelerations which Varied in Force in Comparison with the Initial Values Expressed As a % (According to Data Provided by S. F. Simpura)

Indicators of Initial Respiration	Accelerations			
	6 G's-- 180 sec	8 G's-- 120 sec	10 G's-- 90 sec	12 G's-- 60 sec
MOD in liters/ min	+54.5	+36.5	+44.9	+46.9
Need for O <sub>2</sub> in ml/min	+37.8	+14.0	+19.5	+32.4

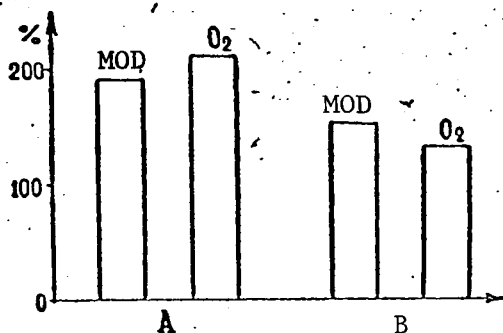
A comparison of materials obtained during single and repeated accelerations indicated that, in the training series, the degree of changes was much less than with repeated accelerations (bar graph). In fact, the increase /9 in the amount of oxygen needed by the animals during the time when rotation was being braked in the 2nd Series in comparison with the initial value was +111% and in the 3rd Series it was only +32%.

The drop in the increase in need for oxygen in animals in this sector of rotation during the tests with repeated accelerations is apparently evidence of the positive effect of training.

Similar changes were recorded with respect to consumption of energy. The level of gas exchange in the 1st and 2nd Series during the accelerations changed relatively little whereas in the period of decrease in strain and full stop of the centrifuge it grew rapidly. In the 3rd Series these changes became more gradual.

A comparative analysis of energy consumption in animals experiencing /10

the single acceleration of 12 G's for a period of one minute and during the training series when the accelerations were repeated indicated that, for a subsequent exposure to the acceleration of the same strength, the animals lost a reduced amount of energy (Table 4).



Mean data of change in amount of air inhaled per minute (liters/min) and need for O<sub>2</sub> (milliliters/min) in dogs during braking of the centrifuge after an acceleration of 12 G's with duration in minutes expressed as a percentage: A--single acceleration; B--in the training series of tests the initial value is taken as 100%.

In this way the results of actual investigation indicate reasons to think that the effects of acceleration acting in a transverse direction causes significant disorders in the gas exchange in the lungs. The intensity of the gas exchange during the after-effects period has a certain dependence on the value and duration of the accelerations and tend mainly to eliminate the oxygen deficiency.

The results we obtained agree with those obtained by M. Ye. Marshak (1961), M. I. Vinogradov (1958), and N. K. Vereshchagin and V. V. Skryabin (1958) who studied the function of external respiration under varying loads of a static and dynamic nature.

Protracted transverse accelerations, causing redistribution of the blood in the organism, can disrupt the blood supply in various organs and tissues and thereby greatly change the oxygen-restorative processes. The cause for /11 such changes may be reduction of the activity of many enzyme systems and the disruption of the transport function of the blood.

By way of tests to reflect the change in the organism of the oxygen-restorative processes, a urinalysis was performed to determine urine creatine, creatinine, and pyruvic acid (PVK) content. The tests were conducted by Ye. A. Abaturova on seven animals in the 2nd and 3rd series. The changes in the indicators mentioned had a phased nature with maximum change on the 1st and then on the 7th--14th days after rotation. After a single acceleration of 12 G's for one minute an increased content of creatine (prior to acceleration it was either absent or existed only in an amount of

Table 4

Change in Energy Consumption in Animals During an Acceleration of 12 G's Lasting One Minute in the Training Series of Tests in kcal/kg of Weight (According to Data Provided by S. F. Simpura)

Time of Measurement	Change in Energy Consumption in Animals in kcal/kg with:		Difference in %
	Single acceleration of 12 G's lasting one minute	Accelerations of 12 G's in the training series	
Initial Values	74.9 + 29.2	81.1 + 11.2	+ 8.0
With Acceleration of the centrifuge	87 ± 33.9	51.4 ± 22.9	-42.0
At the "platform"	91 ± 45	86.1 ± 28.4	7.0
During braking	139 ± 46	116 ± 41.5	17.0
After rotation:			
1st min	104 ± 18.4	85.7 ± 28.4	-12.0
2nd min	81.3 ± 16.9	79.6 ± 25.2	- 2.0
3rd min	95.7 ± 20.7	87.3 ± 26.5	- 9.0
4th--6th mins	76.4 ± 24.5	82.9 ± 16.0	+ 9.0

Note: The values of energy consumption with single accelerations were taken as 100%. After the  $\pm$  signs there are given root-mean-square values. In the table mean data for 8 dogs in each series of tests are given.

13--50 mg/day was found in the urine of all dogs tested on the first day. The level of creatine in the urine of some dogs increased gradually and in others increased spasmodically, reaching 234 mg/day on the 7th--14th days. Later there was noted a decrease in the amount, and restoration of the initial level, as a rule, occurred in 2--6 weeks. In some cases, separation of creatine in the urine normalized on the fourth day after the accelerations had been experienced. During the first hours after the termination of rotation (acceleration of 12 G's for one minute), the amount of creatinine in the urine usually increased to 500--600 mg/day with 140--480 mg/day in the initial condition. In 24--31 hours after rotation there was less in the urine than prior to rotation. On the third day, the amount of creatinine in the urine increased rapidly, reaching its maximum level on the 7th--14th days and exceeding the normal level by 1.5--2 times. In 6 weeks the level of creatinine in the urine of the dogs had subsided to normal limits. It should be stated that the curves indicating the separation of creatine and creatinine coincided or paralleled.

The amount of PVK in the urine one day after rotation decreased, in most cases, by not more than one-third the initial level. On the third day, the level of PVK in the urine exceeded the initial value. The maximum separation of PVK was observed on the 7th--14th days. In many cases, during the first 7 hours after rotation 1.5 times more PVK was separated from the urine of the animals than during the period of one day prior to the time the accelerations were experienced. Six weeks later the PVK content in the urine was within normal limits.

After repeated rotation in the centrifuge, which terminated with an acceleration of the same force and time (12 G's for one minute), changes in the cited biochemical indicators were noticeably more gradual than after a single exposure to acceleration. After repeated rotations no creatine was found in the urine. In one day and after 3--7 days following termination of rotation, the separation of creatinine, in comparison with the initial value, increased by approximately 1.5 times with subsequent normalization. In the majority of case changes in the PVK content after rotation fluctuated within normal limits.

The information obtained by comparing the PVK level in the urine and /12 the glycogen content in the myocardium after the accelerations had been experienced is worthy of note.

According to the information provided by V. G. Petrukhin and M. M. Sokolova the glycogen content in the myocardium 30--60 min after rotation was greatly reduced. By the third day it had normalized and by the 7th had again decreased and then again gradually reached the initial values. The disappearance of glycogen from the myocardium immediately after rotation apparently was caused by an increase in the consumption of it during the accelerations. At the same time a large increase in the amount of PVK in the urine was observed. The subsequent decrease of PVK can be explained by the restoration of the glycogen content. The large increase of creatine, creatinine, and PVK in the urine apparently is caused by disruption of the processes of synthesis in the organism as a consequence of the decrease in activity of many of the enzyme

systems. The occurrences of hypoxia due to the effects of acceleration apparently caused the change in the reaction of the medium and thereby revealed the decrease in the activity of the enzymes of tissue respiration.

It should be noted that the shifts we found proved, in trend, to be similar to the shifts observed in sportsmen subjected to the stresses of strenuous physical activity. (Ye. M. Kozhukhar', 1962; L. Sh. Levina, 1960; A. F. Makarova, 1960; V. A. Ragozkin, 1963; D. A. Chibach'yan, 1963; N. N. Yakovlev, 1960; and others).

The changes in biochemical indicators during the period of after-effects had a phased course. During the first few days after rotation, the changes apparently were the results of disruption of the oxygen balance in the organism during the accelerations. Later changes were probably caused by the changes in the vascular and parenchymatous elements of the tissues and organs and also by the repair processes in the organism.

It is known that an important role in the resistance of an organism to various stress actions is played by the mechanism of nonspecific adaptation. Hormones of the adrenal cortex are one of the main factors in reactions on which the ability of an organism to adapt itself to the harmful effects of an external medium is based.

From available literature, it is known that the effects of acceleration in various regimes may lead to changes characteristic of a state of stress or even dystrophy of an organ (G. A. Arutyunov and others, 1961; A. A. Gyurdzhian, N. N. Demin, 1961). In the opinion of V. D. Polis (1961), the existence of a normal level of corticosteroids facilitates mobilization of protective reactions during the effects of positive accelerations. In case of a rapid decrease in this level the resistance to accelerations is reduced as is also the case with other stress factors.

A study of the reaction of the adrenal cortex based on data reflecting the separation of 17--21-dioxy-20-ketocorticosteroids showed that the effects of acceleration under the conditions used in our tests were a strong stimulus causing a state of great tension in the organism. The materials obtained by M. I. Belyakova after single accelerations of 12 G's for one minute give evidence of the fact that, during the first few days, there was observed in all animals a clearly defined lowering in the level of corticosteroids in the urine (by 100--300%). On the 3rd--7th days after rotation the amount increased and approached the initial level. In the training series of tests, after such acceleration the amount of corticosteroids separated from the urine not only did not decrease but even proved to be 20--29% more in comparison with the initial level, and in one case 98% more. During the next 3--7 days the amount of corticosteroids separated decreased and gradually approached the initial level. /13

Thus, the reaction of the adrenal cortex to single and repeated accelerations varied. Apparently the decrease in the separation of corticosteroids after the effects of a single acceleration of 12 G's for one minute should be considered a result of a certain amount of exhaustion in the adrenal

cortex. The increased separation of corticosteroids after the repeated accelerations during the first few days and, in some animals, for three days after the termination of rotation apparently is evidence of the occurrence in the organism of a condition in which the mechanisms of nonspecific adaptation in response to stress stimuli react fastest.

The investigations made of the peripheral blood (N. I. Konnova), bone marrow (N. A. Yurina), and the lymphoid organs (Yu. I. Afanas'yev, Yu. Mashkovtsev) have made it possible to define many changes which occur after the effects of acceleration. In the peripheral blood an increase in the amount of erythrocytes was found and in the bone marrow, activation of erythropoetic and granulopoetic functions. The increase in the amount of erythrocytes and activation of erythropoiesis are probably caused by hypoxia which developed as a result of the effects of acceleration and were a compensatory reaction of the organism directed toward increasing the oxygen capacity of the blood. The changes in the myelopoetic function of the red marrow were more pronounced in the 1st Series than in the 2nd Series. Activation of erythropoiesis in the bone marrow after an acceleration of 8 G's for a period of 3 min continued for 30--60 days; after an acceleration of 12 G's for one min the erythropoetic function normalized by the 30th day.

Repeated accelerations caused less change than did single accelerations. The amount of erythroblasts in the bone marrow increased only during the first few days and by the third day dropped and later stabilized at a level somewhat higher than normal. This is evidence of the fact that acceleration acting repeatedly creates a condition of mobilized readiness of the erythropoetic /14 function without causing abrupt deviations in it.

The neutrophilic leukocytosis which developed early, during the first hour or during the first few days, after single accelerations is apparently a consequence of mobilization of the prepared granulocytes of the bone marrow. Later activation of neutrophilic granulopoiesis was observed. Neutrophilic leukocytosis which developed in the peripheral blood and the increase in the neutrophilic granulopoiesis in the bone marrow can be explained by the increased demand of the organism for neutrophils. This apparently is caused by the formation of centers of hemorrhaging and the development of destructive processes in the organs demanding mobilization of the protective forces of the organism. Phenomena of compensation developed 30 days after accelerations of 12 G's lasting one minute and somewhat later after accelerations of 8 G's lasting 3 min.

After repeated accelerations, the changes in the blood and the bone marrow early in the after-effects period were similar. However, later, contrary to the effects of single accelerations, there was no abrupt increase in the total number of neutrophilic granulocytes. Their number normalized over a period of 3--7 days. The lymphopenia and eosinopenia noted in the first days of the investigation (up to one day) were evidence of the development of a stress-reaction in the organism.

In this way hematological investigation made it possible to define many changes, the genesis of which was conditioned by the development of oxygen

insufficiency in the organism, a general stress-reaction, and also the formation of centers of hemorrhaging and destructive processes in the organism.

Pathomorphological investigations conducted by V. G. Yelisseyev, Ye. F. Kotovskiy, Yu. N. Kopayev, Yu. M. Afanas'yev, V. V. Korolev, et al. have made it possible to establish in various organs and systems the occurrence of approximately uniform changes which affect the vascular system and parenchymatous elements. The most significant changes developed in the organs having the greater mass and an abundance of blood (lungs, liver, brain, and kidneys). It was found that the degree of change which occurred in the organs increased in proportion to the effects of acceleration. The changes observed had, in most cases, a reversible nature, showing complete compensation by the 30--60th days.

It was found that, under the conditions of our tests, the degree of damage to the organs depended mainly on the time during which the effects of acceleration were experienced and, to a less extent, on the force of acceleration. One exception was the lungs where pathological changes increased with an increase in the force of the acceleration.

With respect to the vascular system there were observed occurrences of venous congestive hyperemia accompanied by dystrophic processes in parts of the vascular wall, hemorrhaging, and, in many cases, the formation of thrombi. Fresh hemorrhaging occasionally occurred 1--3 days after rotation. This found confirmation in tests conducted with subjects who exhibited blood flowing 15 from the nose not immediately after the effects had been felt but rather 14--18 hours later. Such hemorrhaging was observed only after the effects of acceleration, maximum in duration (8 G's for 5--6 min). It should be noted that after repeated effects of acceleration some adaptation was manifested in the vascular system of the organism.

Histochemical investigation with a determination of the quantitative content in the cells of nucleic acids revealed a two-phase change in the ribonucleic acid (RNK) content in the nucleoli and cytoplasm of cells: a decrease in the amount of RNK in the cytoplasm (1st--3rd days) with a subsequent increase to the normal level (7th--14th days). The drop in the amount of RNK apparently occurred as a result of the occurrence of hypoxia in the organism. The subsequent increase in RNK in the nucleoli and the cytoplasm of the cells is evidence, probably, of the increased functional activity of the cells during the period of development of the compensatory phenomena. A change was found in the activity of several oxidizing enzymes during the first few hours after the effects of acceleration had been experienced. This is in agreement with data from electronic microscopic observation of the mitochondria of cells.

Thus, an integrated study of the processes occurring in the organism of animals under the influence of transverse accelerations permits the conclusion that, due to the effects of such acceleration in an organism, various changes, a hypoxic state, a stress-strain reaction, and the effects of the acceleration itself occur which lead to changes in the organs. Among these pathogenetic factors, the main role is performed by circulatory and hypoxic

hypoxia.

The research which was conducted established a correlation of changes in the roentgenological, clinical, and pathomorphological pictures. In various organs and systems of an organism, signs of development of primarily adaptive reactions were found. With repeated effects of acceleration, the changes in the function of external respiration, the energy consumed by the animals, and the changes in the hematological and biochemical indicators revealed traces of development of adaptive reactions. At the same time pathomorphological investigation gives evidence of the occurrence in various organs and tissues of structural damage which varies in course. Under the condition of our tests it was established that the degree of damage suffered in a majority of the organs and tissues which were examined proved to be more extensive with an acceleration of 8 G's for 3 min than for an acceleration of 12 G's lasting for 1 min. Simultaneously the degree of pathological changes in the pulmonary tissue increased with an increase in the acceleration. In the lungs of animals subjected to repeated accelerations, focal proliferation in the connecting tissue was observed as early as one day after the termination of rotation. After single accelerations microscopic proliferation in the connecting tissue was noticed only on the 30th--60th days (Yu. N. Korolev, /16 1965).

Therefore, the repeated effects of acceleration in the organism of an animal may cause various effects which, on one hand, have an adaptive nature and, on the other, a clearly expressed cumulative damaging nature to occur. A thorough study of this problem to establish the optimal systems of accelerations, their values, duration, frequency, etc. remains an important task, the performance of which is of great practical scientific importance.

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